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3D Model of Tunku Tun Aminah Library Using Unmanned Aerial Vehicle (UAV)

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Abstract: 3-Dimensional (3D) modelling helped bring flat, 2D ideas to life. 3D models were valuable because they could include a much wider array of project information. The purpose of this study was to develop a 3D model by using Unmanned Aerial Vehicle (UAV) images of Tunku Tun Aminah (PTTA) Library building. To create a 3D model, Agisoft Metashape software combined photos from UAV images. Then, we assessed the accuracy of the 3D model of Tunku Tun Aminah's library building to the actual scale of the building from a vertical and horizontal view. The result of the 3D model that has been constructed demonstrates a high level of accuracy in capturing its intricate details and spatial characteristics. The vertical and horizontal views, both the Tunku Tun Aminah library and the parking lots had actual lengths that matched the estimated values precisely. The results indicated that there were slight differences in measurements, and all the measurements were 95% accurate and above. The precision demonstrated in capturing the dimensions of these structures indicates reliable data for analysis and decision-making purposes. The Ground Sampling Distance (GSD) for the assessment was 1.36 cm per pixel. At the end of this research, the 3D model of PTTA library was uploaded on SketchFab to allow various parties, including university authorities, contractors, local authorities, architects, and structural engineers to have a better understanding of the building's condition and its surroundings.

Keywords: 3D Model, assessment, Tunku Tun Aminah (PTTA) library, UAV

1. Introduction

3D modeling in civil engineering played a crucial role for engineers and clients. It provided a built-in illustration of the project's scope, eliminating the need for sifting through drawings and patterns [1]. The benefits of 3D modeling, such as cost savings and simpler design manipulations, were evident. Stress mapping highlighted design flaws, and unlimited model inspection ensured every defect was identified and corrected. The enhanced visualization allowed for simple verification of physical changes, functional changes, and aesthetics. Collaboration among design teams improved, and 3D modeling reduced the time and labor involved in developing newer esign versions [2].

This study concentrated on constructing a 3D model of Tunku Tun Aminah Library at the University Tun Hussein Onn Malaysia. A DJI Phantom 4 Pro drone captured aerial photographs, and Agisoft Metashape software was used for the modeling. Ground Control Points (GCPs) were positioned, and their coordinates were measured for accuracy. Data collection employed a systematic approach, ensuring comprehensive coverage of the area. The generated 3D model was

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compared to the actual length of the building to assess its accuracy and reliability in representing the physical dimensions.

The resulting 3D model of Tunku Tun Aminah Library was uploaded to Sketchfab, a platform for sharing 3D artwork. This permitted the model to become a benchmark for further 3D modeling projects within the library and university facilities. It facilitated improved understanding of the building's condition and surroundings for contractors, local authorities, architects, and structural engineers. The versatility of the 3D model enabled it to be viewed and interacted with on various digital devices, providing a comprehensive visualization experience. This had the potential to simplify and reduce the cost of future urban planning [3].

1.1 3-Dimensional Model

The process of constructing a three-dimensional representation of an object using specialist software was referred to as "3D modelling." In this process, a 3D model was created to portray the object's size, shape, and texture. The data collected was processed digitally using computer tools. Two primary methods were used to reconstruct the 3D model: contact and non-contact methods. The non-contact approach involved using a laser scanner or camera to scan or capture images of the object, while the contact method relied on manual measurements using a tape measure and ruler to estimate dimensions. Non-contact methods proved to be more cost-effective, speedier, and simpler compared to contact methods in modern times [4].

1.2 Unmanned Aerial Vehicle

Unmanned Aerial Vehicles (UAVs) have become cutting-edge aircraft designed to navigate autonomously without a pilot. Equipped with a range of sophisticated features, including on-board GPS, microchip autopilot with a stabilizing 3-axis gyro sensor and magnetometer, and the ability to track UAV telemetry at GCPs, these vehicles offer exceptional capabilities. They have emerged as a highly sophisticated technology, providing an ideal platform for various applications such as mapping, topographical surveys, remote sensing research, and aerial photography [5].

UAVs are extensively used for duties like slope mapping, building and city modelling, monitoring forest fires, road assessment, vehicle detection, disaster management, and urban/suburban mapping. The combination of close-range photogrammetry, airborne mosaic imaging, and terrestrial photogrammetry is known as UAV photogrammetry, a part of the geomatic applications used to compute and map the Earth's surface. UAV photogrammetry provides a cost-effective alternative to conventional human aerial photogrammetry and enables real-time and automatic applications [6].

1.3 Agisoft Metashape

Agisoft Metashape, formerly known as Agisoft PhotoScan, was a potent and versatile software used in photogrammetry. It processed digital images to generate high-quality 3D models, point clouds, and orthomosaics, utilizing advanced algorithms and cutting-edge technology to reconstruct objects and scenes from a collection of 2D photographs [7]. The software excelled at generating accurate and detailed 3D models by employing a process called dense point cloud generation, which identified critical locations in the images and created a dense network of 3D points, capturing the subject's shape and geometry precisely [8].

Additionally, Agisoft Metashape offered a range of tools for refining and augmenting the models, including filters, editing techniques, and texture mapping. It supported both automated and manual workflows, providing flexibility, and had a user-friendly interface that simplified the complete photogrammetry process. The software could handle large datasets, making it appropriate for projects involving extensive image capture like aerial surveys, architectural documentation, or cultural heritage preservation. Its comprehensive processing capabilities ensured efficient and reliable results [9].

2. Materials and Methods

The process of constructing and analyzing the 3D model of Tunku Tun Aminah's library can be divided into four distinct phases: setting up ground control points, data collection, construction of 3D model, and validating the accuracy of the 3D model.

2.1 Phase 1: Set up Ground Control Point (GCP)

In this project, the first stage after determining the problem statement, objectives, and scope was to set up GCPs. The GCPs served as reference points to establish accurate photogrammetric data for constructing the 3D model. GCPs were chosen to be 500mm x 500mm in size for visibility and simplicity of marking on images before flight processing. A total of 14 GCPs were used, with seven located on the ground around the Tunku Tun Aminah's library building and seven on the building itself to account for elevation variations and enhance model accuracy.

Using at least five GCPs for the flight area was regarded best practice, as it minimized the risk of errors and ensured more accurate results [10]. The GCPs were located strategically, with one GCP within the mapping area to prevent a phenomenon called doming, where accuracy decreases with distance from the GCP. Red and white colors were chosen for the GCPs due to their reliability and long-standing use as standards. The effectiveness of the GCPs was dependent on their distance from the user, with areas near the GCPs generating the most accurate results [11].

To set up the GCPs, we used a combination of clear colors, such as spray paint with red and white pigments, and nails. Additionally, we utilized the triangular red mark on Tunku Tun Aminah's library windows as a control point, as depicted in Figure 1. The GCPs needed to have greatly contrasting colors to distinguish them from the surroundings. The GCPs were marked by placing a roofing nail in the center on the ground, making them readily identifiable during the data collection process. Figure 2 depicted the 14 GCPs around the study area.

(a) (b)

Fig. 1 - (a) Ground control point around the building; (b) Control point at the building

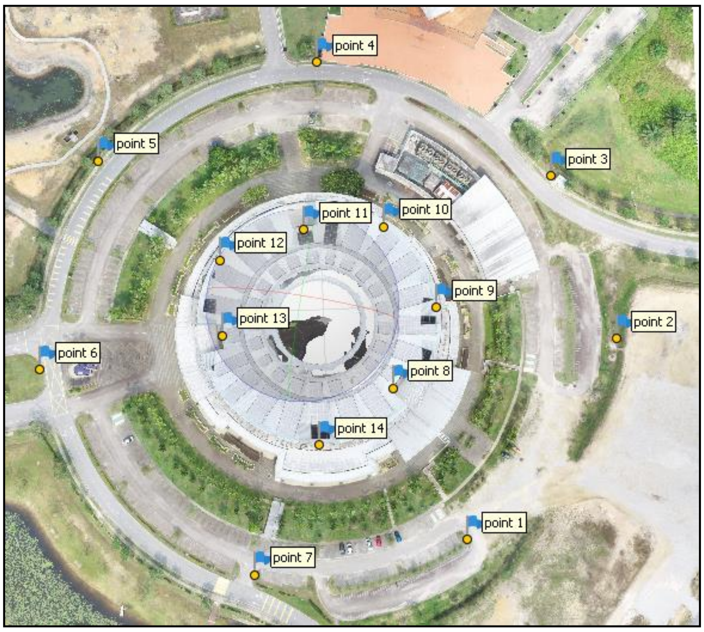

Fig. 2 - Location of total 14 GCPs

2.2 Phase 2: Data Collection

Equations After setting up the GCPs, the data collection procedure began. The positioning of the GCPs was determined using the GNSS Topcon Hiper V system, which provided precise coordinates through satellite transmissions. The GCPs were marked on the ground and served as reference points for the aerial survey using photogrammetry techniques. For the data collection, a total of 14 GCPs were determined, with GCP 1 until GCP 7 on the ground and GCP 8 until GCP 14 on the building. The coordinates of GCP 8 until GCP 14 on the building were calculated using bearing and distance with reflector less observation. The reflector-less method utilized a red laser beam for measurements, and points with readily identifiable features were chosen for accuracy.

The flight path of the UAV was planned in a grid and circular pattern to acquire clear and sufficient photos as shown in Figure 3 and Figure 4. The weather conditions were clear, and the UAV captured as many images as possible to enhance accuracy. To construct a 3D model using photogrammetry, factors such as image overlap, angles between images, number of flights, and drone speed were crucial. It was recommended to have a minimum of 60% overlap between images, with carefully set angles and multiple flights at various heights. A moderate drone specification assured clear images with minimal motion blur.

Fig. 3 - Planned flight path from plan view in grid motion

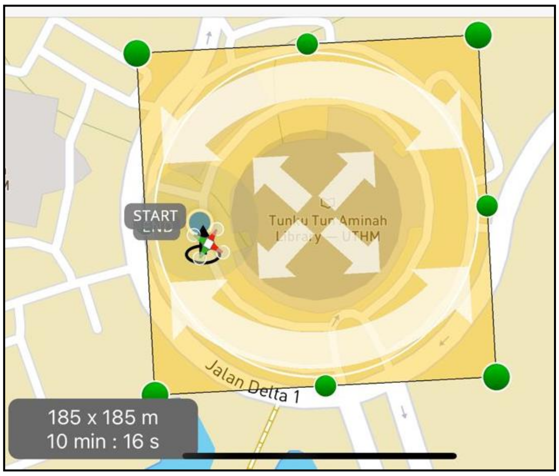

Fig. 4 - Planned flight path from plan view in circular motion

2.3 Phase 3: Construction of 3D Model

To construct a 3D model of Tunku Tun Aminah library using Agisoft Metashape, it begins by importing the photographs taken during the aerial survey into the software. Next, reference points known as GCPs are marked on the photos to establish accurate positioning. The software then coordinates the photos based on their features and overlapping areas, determining camera positions and orientations.

Once aligned, a 3D mesh is created, creating a basic framework of the model. Textures or hues from the original photos are applied to the mesh to make it visually realistic. A Digital Elevation Model (DEM) is then generated, representing the height and topography of the terrain and objects in the model. Finally, an orthomosaic, which is a corrected and scaled 2D aerial image, is constructed to provide an accurate representation of the entire surveyed area. The procedure concludes with the completion of the 3D model of Tunku Tun Aminah library. The overall workflow is indicated in Figure 5.

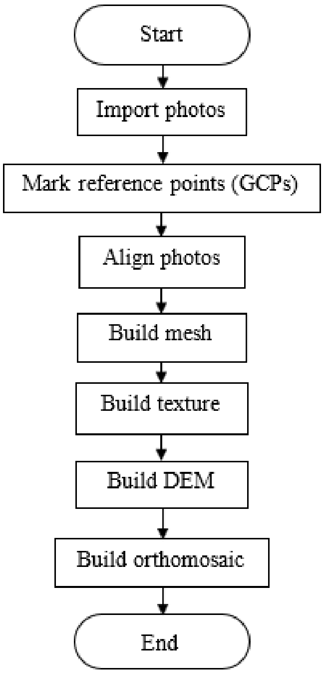

Fig. 5 - Workflow of create 3D model using Agisoft Metashape

2.4 Phase 4: Validating the accuracy of the 3D Model

After constructing the 3D model of the Tunku Tun Aminah building, its accuracy was validated by comparing it to actual measurements. Markers were placed on the model, and the reference length of the building was determined using the Agisoft Metashape. A scale icon within Agisoft Metashape was used for this purpose. The UAV mapping results obtained from the 3D model were then compared to the measurements derived from architectural drawings. The analysis focused on both the vertical and horizontal views of the building, as well as the dimensions of the parking lots encircling the building. By comparing the model to the actual measurements, the study intended to assess the accuracy of the model and verify its adherence to real-world dimensions.

3. Result and Discussion

Based on the methodology outlined in section 2.3, a textured 3D model of Tunku Tun Aminah library was generated. The resulting model comprised two forms of output: point cloud and textured (as shown in Figure 6). These outputs allowed for estimating the length of the building and undertaking an accuracy analysis by comparing the 3D model to the actual structure.

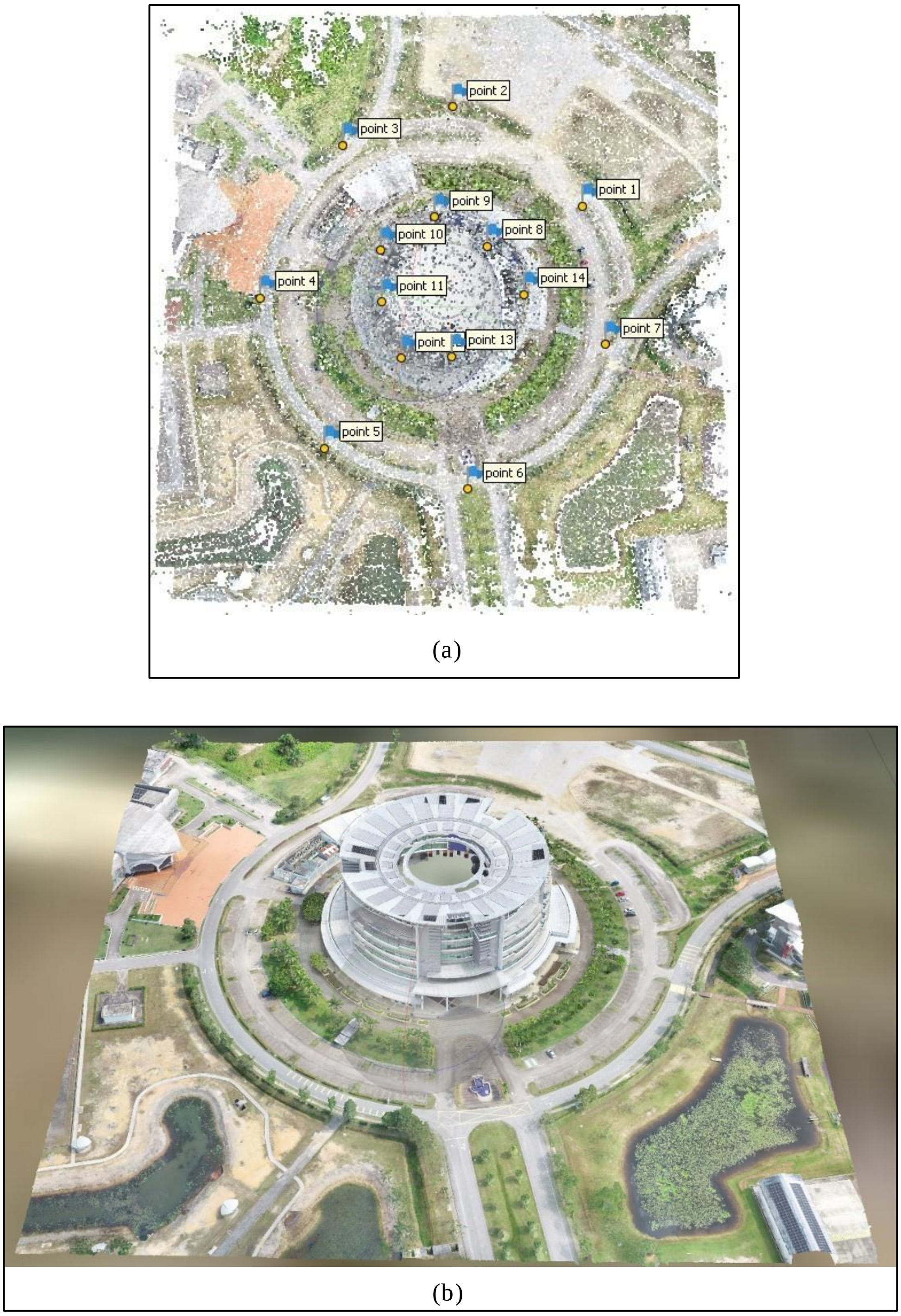

Fig. 6 - Tunku Tun Aminah library form type; (a) Point cloud; (b) 3D textured

The UAV mapping results obtained from the 3D model were compared with the actual measurements derived from architectural drawing plans. The accuracy analysis focused on two primary aspects: the vertical view and the horizontal view of the building. Additionally, the three parking lots surrounding the building were also included in the validation procedure. Accuracy is calculated using the equation depicted in Equation 1 [12].

$$\text{Accuracy} = 100\% - \left(\frac{|\text{Actual Length-Estimation Length}|}{\text{Actual Length}}\ x\ 100\%\right) \qquad (1)$$

The survey results indicated that the measurements taken were highly accurate. In the vertical and horizontal views, both the Tunku Tun Aminah library and the parking lots had actual lengths that exhibit remarkable high values to estimated measurement. The results indicated that there were slight differences in measurements, and all the measurements were 95% accurate and above. The precision demonstrated in capturing the dimensions of these structures indicates reliable data for analysis and decision-making purposes. Table 1 represents the accuracy of all measurements.

Table 1 - Data measurements

Parameter		Actual length (m)	Estimation length (m)	Differences (m)	Accuracy (%)
Tunku Tun Aminah library	Vertical view	33.90	33.40	0.50	98.53
	Horizontal view	80.00	79.60	0.40	99.50
Parking Lot A	Length	4.80	4.70	0.10	97.92
		26.00	25.30	0.70	97.31
Parking Lot B	Length	4.60	4.53	0.07	98.48
		26.20	25.90	0.30	98.85
Parking Lot C	Length	4.60	4.54	0.06	98.69
		20.60	20.00	0.60	97.09

Moreover, the analysis revealed that the ground sampling distance (GSD) increased as the flight altitude increased. Circular flights were conducted at heights of 15 meters, 30 meters, and 45 meters, resulting in corresponding GSDs of 0.41 cm/px, 0.82 cm/px, and 1.23 cm/px, respectively. This indicates that as the drone flew at higher altitudes, each pixel in the acquired images represented a larger ground area, leading to a reduction in image detail and resolution. In addition to circular flights, a grid flight was performed at a height of 50 meters, resulting in a GSD of 1.36 cm/px. The grid flight entailed systematic coverage of the survey area by flying the drone in parallel lines both horizontally and vertically.

The varying flight heights and corresponding GSDs allowed for the capture of data with various levels of detail and resolution. Higher flight altitudes were effective in effectively covering larger areas, while lower flight altitudes provided finer details and higher-resolution imagery. The combination of circular and grid flights in the flight plan provided a comprehensive dataset for the detailed analysis and mapping of the surveyed area. It considered the trade-off between flight height and image resolution, ensuring a balance between capturing extensive coverage and obtaining sufficient detail in the aerial imagery.

4. Conclusion

The conclusions of this study are as follows: Objective 1, which involved constructing a 3D model of the Tunku Tun Aminah Library using a UAV and Agisoft Metashape software, has been successfully achieved. The resulting model is highly accurate, depicting intricate details and spatial characteristics of the library. It consists of millions of faces and vertices, providing a comprehensive representation of the structure. The use of reconstruction parameters and texturing techniques, such as depth maps, interpolation, and texture mapping, enhances the model's accuracy and visual fidelity. This accurate 3D model can be utilized for architectural analysis, virtual excursions, and preservation efforts, offering valuable insights and immersive experiences.

Objective two was focused on validating the accuracy of the 3D model, and the findings support its reliability. The survey results demonstrate a remarkably high level of accuracy, with the measured dimensions closely matching the estimated values with minimal differences. This indicates that the 3D model faithfully represents the tangible dimensions of the library. Nevertheless, the presented method still has limitations that require further exploration, such as the potential impact of varying wind patterns on UAV flight stability, and need more discussion, for example, the trade-off between real-time obstacle avoidance and energy-efficient route planning. Additionally, while this work acknowledges the endurance limitation of UAVs and integrates energy consumption into the Constrained Path Planning (CPP) framework to optimize flight paths, it's essential to recognize that challenges linked to dynamic weather conditions and their implications for energy-efficient routing remain relatively uncharted in prior research. Moreover, careful consideration must be given to the influence of real-time obstacles on the effectiveness of the proposed battery supply points. The intricate interplay between obstacle avoidance and energy conservation could profoundly affect the overall system efficiency. Further investigation into these facets is imperative to gain a comprehensive understanding of the method's applicability and to identify potential areas for refinement. By addressing these aspects, which have been limitedly explored in previous studies, this work contributes to the advancement of UAV-based 3D modeling techniques.

The contributions of this study are as follows: Architects and designers can rely on the model for detailed analysis and planning, as it closely parallels the physical actuality of the library. Additionally, the accurate 3D model facilitates immersive virtual tours, allowing users to investigate the library's layout and structure digitally. It also functions as a valuable tool for preservation efforts, aiding in documentation, restoration, and conservation initiatives. Researchers can confidently analyze the significance of the model's architectural features, benefiting from its precision and reliability. In summary, the 3D model of the Tunku Tun Aminah Library exhibits an exceptional level of accuracy. Its precise representation of the library's dimensions makes it a valuable instrument for architectural analysis, virtual tours, and preservation efforts, providing users with confidence in its fidelity to the physical structure of the library. Also, the popularity of UAVs in urban planning is on the rise, and rightfully so. These devices are capable of capturing detailed images of cities or structures, offering urban designers and planners a thorough understanding of the region. This proves especially advantageous for significant undertakings such as urban revitalization or new architectural endeavors. All in all, incorporating UAVs into urban planning brings multiple benefits when contrasted with conventional surveying techniques.

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